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SATELLITE MEASUREMENTS OF MARITIME AEROSOL PARAMETERS

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SUMMARY

A two-channel analysis has been made of NOAA-6 AVHRR data obtained at Barbados in 1980 in conjunction with multispectral ground truth sunphotometer measurements of the aerosol optical thickness. The AVHRR Channel 1 (0.65 μm) and Channel 2 (0.86 μm) radiances were used to infer the aerosol optical thickness and the Junge size distribution parameter ν, and were compared with the corresponding ground truth values. The analysis has shown, in spite of uncertainties in the accuracy of both the ground-truth and the satellite data, that the AVHRR Channel 1 and Channel 2 radiances can provide useful estimates of ν to support the aerosol content estimates previously demonstrated. The quality of the data available for this study was less than desirable, and it is recommended that a ground-truth network with reliable instruments and observers be established as soon as possible to verify the two-channel analysis on a global basis. The preferred satellite for the experiment would be the NOAA-7 which has a 1430 equator crossing. The 1430 orbit would permit observations year-round rather than just in the summer months, as with NOAA-6.

ACKNOWLEDGMENTS

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1. INTRODUCTION

The atmospheric marine boundary layer is of considerable importance to Navy operations. Of particular interest, with the development of laser communications and electro-optical weapons systems, is the nature and distribution of aerosols over the oceans. At the present time measurements of aerosols over ocean areas are very infrequent. Science Applications, Inc. (SAI) has been developing(1,2,3) a satellite technique to measure aerosols over the ocean. This technique relates the upwelling visible radiance measured by the satellite to the aerosol optical thickness of the atmosphere. Since 60% of the aerosols are typically in the lowest 1 km, and 90% in the lowest 3 km, it is clear that the satellite measurement will provide information of considerable importance to Navy operations. The satellite technique, originally based on Landsat data, has since been applied to data from other satellites. In our recent NOAA study(4), a ground-truth experiment was conducted with the NOAA-6 satellite at ten sites, in the summer of 1980, to investigate the possible variability of the radiance-aerosol optical thickness relationship around the globe.

SAI recently(5) extended the capability of this technique with the preliminary development of a method using the NOAA-6 AVHRR Channels 1 and 2 radiance data to infer aerosol size distribution information in addition to a more accurate aerosol optical thickness. This has great potential in the use of satellite data to routinely predict the useful range for FLIR systems, and other electro-optical systems, over the oceans.

The present study uses NOAA-6 AVHRR data and coincident ground-truth multispectral measurements of the aerosol optical thickness obtained at Barbados during the 1980 NOAA experiment(4), in order to further investigate the two-channel technique to infer the aerosol size distribution.

The continued development of this technique can ultimately lead to a computer code to automatically convert the measured satellite radiances to global ocean maps of aerosol optical thickness (as a function of wavelength),

surface visibility, predicted slant range, and a size distribution parameter if desired. In addition to the routine production of daily global aerosol maps for Naval operations, the data could be used to build a climatology base for aerosol properties over the oceans for use in Navy systems planning.

2. BACKGROUND

We showed some years ago[6] that it should be possible to make satellite observations of the aerosol optical thickness of the atmosphere using radiance measurements over the ocean. Calculations showed that a linear relationship exists between the upwelling visible radiance measured by a satellite over the ocean, and the aerosol optical thickness of the atmosphere. The technique is most useful over water surfaces since they have a low reflectance (close to zero) so that the upwelling radiance is essentially all due to atmospheric scattering. Over land surfaces, which have much larger albedos, the upwelling radiance is mostly reflected from the surface, and is not very sensitive to change in the atmospheric aerosols. Radiance data from Landsat 1[1], Landsat 2[2], NOAA-5 and GOES[3] have been used with sunphotometer ground truth data to demonstrate that a linear relationship exists between the radiance and the aerosol content. Figure 1 shows the results obtained at San Diego for Landsat 2 overpasses. These studies were supported by theoretical calculations to investigate the effect of varying aerosol optical properties, such as size distribution and refractive index, and other parameters such as vertical distribution, surface reflectivity, wavelength, sun angles and satellite viewing angles.

In order to investigate the general applicability of the technique to different locations, a global-scale ground truth experiment[4] was conducted in 1980 with the AVHRR sensor on NOAA-6 to determine the relationship at ten ocean sites around the globe. The NOAA-6 AVHRR was chosen for this experiment because it provides daily coverage, it has a narrow spectral bandpass (0.65 μm) in the visible region (almost identical to the Landsat MSS 5), and has 1 km spatial resolution. In order to compare the AVHRR radiance-aerosol content relationship with that found previously for the MSS 5, theoretical calculations were made with the Dave[7] atmospheric scattering code to account for the off-nadir scanning of the AVHRR in comparison to the nadir viewing of the MSS. The atmospheric model used aerosol parameters

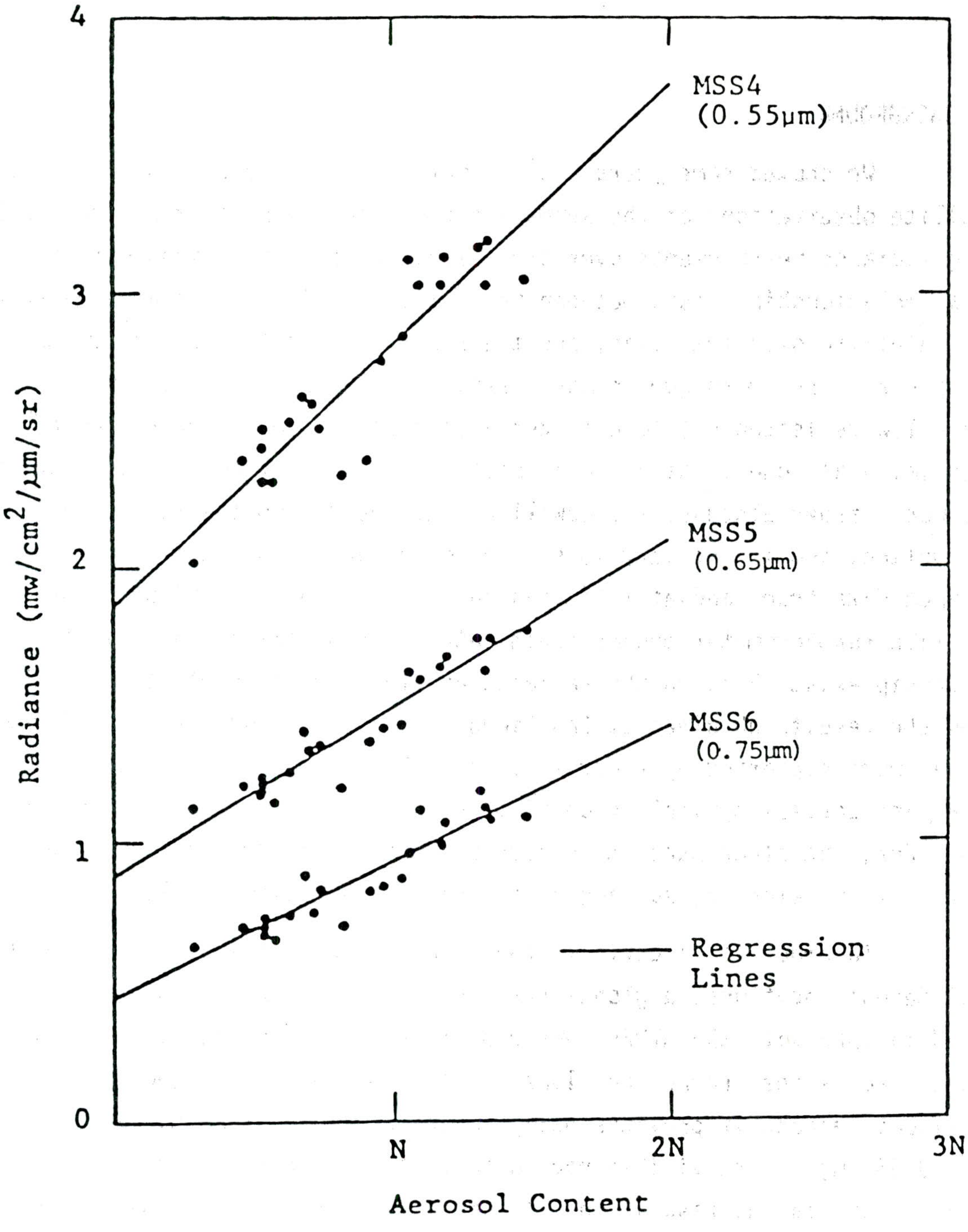

Figure 1. Landsat 2 Ocean Radiances Versus Aerosol Content (N = aerosol optical thickness, 0.213 at 0.5 μm). The radiances are for nadir viewing normalized to a sun zenith angle of 63°.

such that the theory reproduced the linear regression between radiance and aerosol content found for MSS 5. The results of the calculations were incorporated into a table-look-up algorithm so that the AVHRR radiance measurement together with the scan angle and sun angles can be used as input to obtain the aerosol content. The ground-truth measurements of aerosol content were made at the time of the NOAA-6 overpasses (approximately 0730 l.s.t.) with hand-held sunphotometers at ten sites in close proximity to the ocean. The ground truth sites and their locations are listed in Table 1.

Table 1. Ground Truth Sites

Site	Longitude	Latitude
Azores	27° 03' W	38° 43' N
Barbados	59° 30' W	13° 10' N
Diego Garcia	72° 29' E	7° 21' S
Fanning Island	159° 23' W	3° 54' N
Guam	144° 50' E	13° 33' N
Kadena	127° 46' E	26° 21' N
Midway	177° 23' W	28° 12' N
Sable Island	60° 01' W	43° 56' N
San Diego	117° 16' W	32° 45' N
San Juan	66° 00' W	18° 27' N

The data for four sites in the 1980 experiment have been analyzed. The results for three sites, viz., San Diego, Sable Island and San Juan, are shown in Fig. 2 in comparison with those for the USNS Hayes[5] obtained in the Atlantic off the Virginia coast in April 1980. The results for the fourth site, Barbados, are shown in Fig. 3, and suggest that the AVHRR is significantly overestimating the aerosol content. However, as discussed

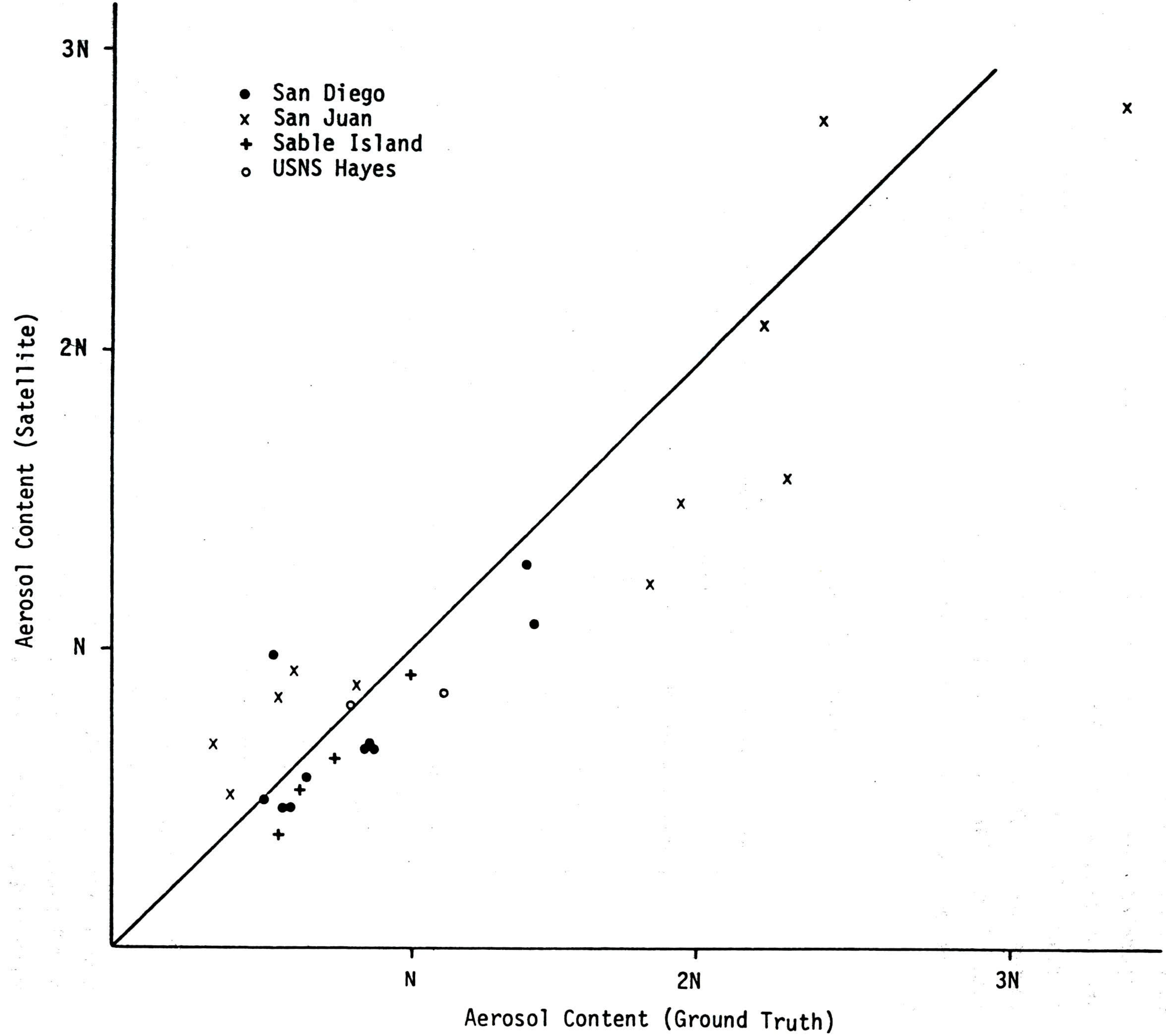

Figure 2. Comparison of AVHRR and Ground Truth Measurements of Aerosol Content (for $\theta_o < 70°$).

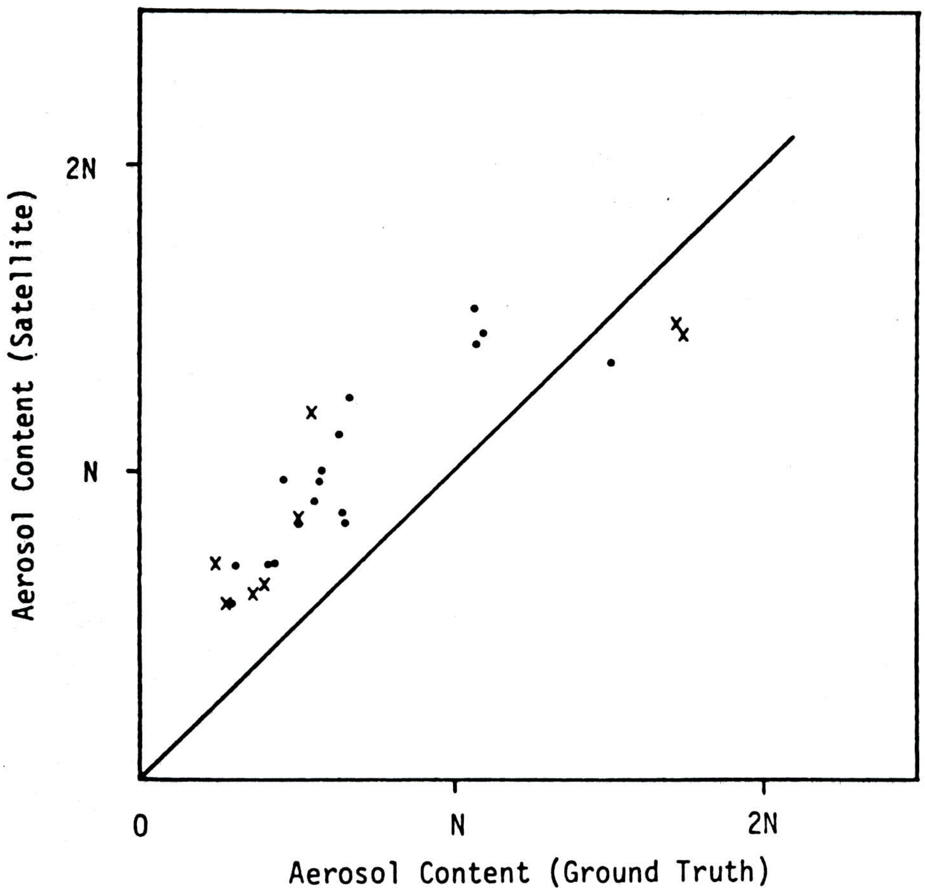

Figure 3. Comparison of AVHRR and Ground Truth Measurements of Aerosol Content at Barbados (Sunphotometer I_o = 176). (x indicates $\theta_o > 70°$.)

in detail elsewhere[4] and in Section 5 of this report, the discrepancy is almost certainly due to a problem in the sunphotometer.

The USNS Hayes data were used in a preliminary investigation[5] of the use of AVHRR Channels 1 (0.65 μm) and 2 (0.86 μm) to infer the Junge size distribution parameter (ν) in addition to the aerosol content. In order to infer ν from the satellite data the Channels 1 and 2 radiances (after correcting the Channel 2 radiance for water vapor absorption) are compared with the theoretical radiances for the sun and view angles at the time of the measurement. Model values of N and ν are chosen so that the model radiances agree with the measured radiances in both AVHRR channels. A comparison of ν from the AVHRR data and from the multispectral USNS Hayes ground-truth is shown in Fig. 4.

The AVHRR radiances used in the above results are corrected empirically, based on a comparison of Channel 1 and Channel 2 radiances[4]. The measured AVHRR radiances are corrected by adding 0.5 mw/cm^2/μm/sr to the Channel 1 values, and by subtracting 0.25 mw/cm^2/μm/sr from the Channel 2 values. It is important to note that these corrections were derived independent of any radiance-aerosol content relationship.

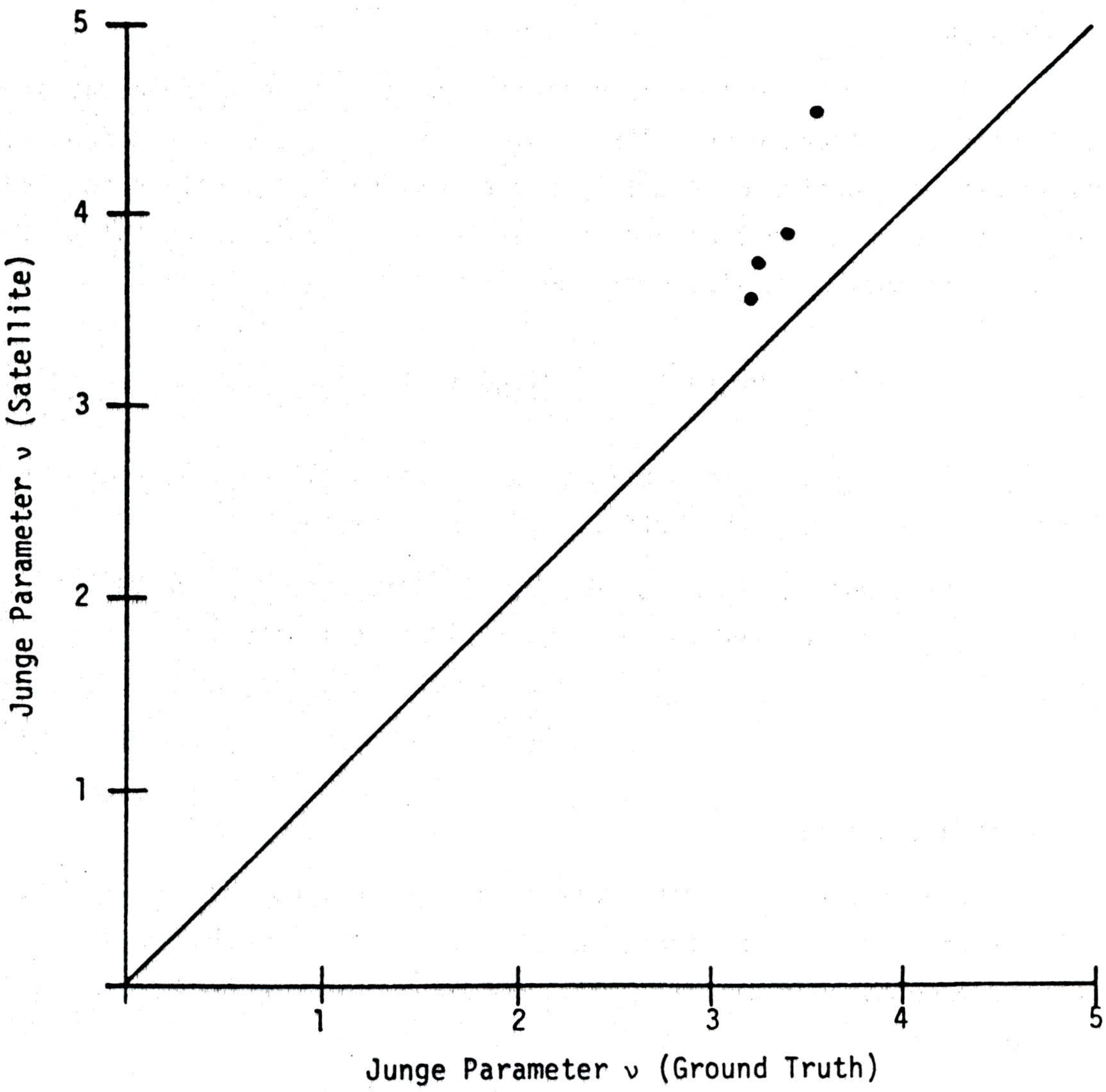

Figure 4. Comparison of AVHRR and Ground Truth Measurements of Aerosol Size Distribution (USNS Hayes).

3. APPROACH

In order to further investigate the two channel technique of determining both N and ν from AVHRR data, the Barbados data set (28 over-passes) has been analyzed in detail since only this data set in the 1980 experiment had multispectral ground truth data suitable to calculate the value of ν in the Junge size distribution:

$$dn(r) = Cr^{-\nu} \; d \log r \; (cm^{-3}) \tag{1}$$

where n(r) is the number of particles with radius r, and C is a constant depending on the number of particles per unit volume.

The ground truth multispectral measurements of aerosol optical thickness (τ_A) are related to ν, to a close approximation, by:

$$\tau_A = B \; \lambda^{-(\nu-2)} \tag{2}$$

where B is a constant.

The ground truth measurements of τ_A included 0.5 μm and 0.86 μm so that a value of ν using these wavelengths is given by Equation (2), and is directly comparable with the value inferred from the AVHRR data at 0.65 μm and 0.86 μm.

The value of ν is inferred from the satellite data by comparing the Channels 1 and 2 radiances (the Channel 2 radiance is corrected for water vapor absorption) with model calculations of these radiances, made as a function of N and ν for many sets of sun and view angles. The values of N and ν are determined so that the model radiances agree with the measured radiances in each AVHRR Channel for the given sun and view angles at the time of the measurement.

This analysis was previously done manually by examination, and interpolation/extrapolation, of the tabulated theoretical radiances, but for extensive use the procedure must be incorporated into a table-look-up code as was done[4] for the single channel analysis of the AVHRR data. In order to do this, additional model calculations were made for both channels in order to make the interpolation/extrapolation procedure more accurate.

The water vapor correction for the Channel 2 radiance consists of dividing the radiance by a constant water vapor transmission factor of 0.86. This factor has an uncertainty of ±0.07 (for typical water vapor amounts found in the atmosphere), as discussed in detail by Griggs[5].

4. TWO-CHANNEL TABLE-LOOK-UP DEVELOPMENT

The development of the two-channel table-look-up code (TLU2) is similar to that used for the Channel 1 table-look-up code (TLU1)[4]. The TLU1 was developed specifically for NOAA-6 AVHRR data obtained in the 1980 experiment. Calculations for the NOAA-6 orbit showed that at the sites listed in Table 1, the range of possible sun angles is:

Sun Zenith θ_o: 51°-87°

Sun Azimuth ϕ: 140°-180° and 0°-40°

The sun azimuth range 0-40° is not considered since sun-glint might occur in this direction. The maximum useful range of scan angles (θ) for the radiometer is considered to be 0-60°.

It was found in our Landsat study[8] that the MSS (0.65 μm) radiances could be modelled with the Dave atmospheric code[7] by assuming that the surface albedo (A) is 0.015, and that the aerosols have a refractive index n = 1.5, and a Junge size distribution parameter ν = 3.5. The range of aerosol contents (N) chosen was 0-10N to include those values anticipated in Saharan dust outbreaks over the Atlantic.

Thus, for TLU2, further calculations were made for ν = 2.0 and 5.0 at 0.65 μm, and for ν = 2.0, 3.5 and 5.0 at 0.855 μm (Channel 2 of AVHRR); a surface albedo A = 0 was used at 0.855 μm based on the Landsat results[8]. The ranges of parameters for the radiance calculations are summarized in Table 2. The choice of increments in the different parameters is based on ease of interpolation between calculated radiances, and to some degree on computational constraints of the Dave code.

The set of radiances calculated for each ν value are stored in the same format as used in TLU1, viz., for each θ_o (=42(6)84°) there are seven values of N (0, 1, 2, 4, 6, 8, 10), and for each N there is a matrix

Table 2. Values of Parameters in TLU2 Radiance Calculations

0.65 μm:	A	$= 0.015$
0.885 μm:	A	$= 0$
	n	$= 1.5$
	θ_o	$= 42(6)84°$
	θ	$= 0(6)84°$
	ϕ	$= 140(10)180°$
	N	$= 0, 1, 2, 4, 6, 8, 10$

of radiance values (R) as a function of θ (=0(6)84°) and ϕ (=140(10)180°). Thus, in TLU2 there are six tables (3 ν's in each of 2 channels) compared to the single table in TLU1. Although radiances for only 3 ν's are stored, the code does compute radiances for $\nu = 0$ and $\nu = 7.0$ using a three point Lagrangian fit to the values at $\nu = 2.0$, 3.5 and 5.0. This extrapolation capability was included as a result of some test cases used in developing the code as described below.

It should be noted that these calculations are for a flat earth model, so that for θ and θ_o greater than about 70°, the radiances would be different for a curved earth model. Thus, in using ground truth in checks on these calculations, special attention should be given to the large values of θ and θ_o.

In TLU1, the following steps are taken to determine N from a given set of values R_p, θ_{op}, θ_p and ϕ_p (all interpolations use the three-point Lagrangian method):

1. Select 3 θ_o's: $\theta_{o1} < \theta_{o2} < \theta_{o3}$ with θ_{op} closest to θ_{o2}.

2. For θ_{o1}, θ_{o2} and θ_{o3} determine R (θ_p, ϕ_p) vs N interpolating between the tabulated values of R (θ, ϕ) as necessary.

3. For each N value interpolate between R $(\theta_{o1}, \theta_p, \phi_p)$ and R $(\theta_{o2}, \theta_p, \phi_p)$ to obtain R $(\theta_{op}, \theta_p, \phi_p)$ vs N.

4. Determine N corresponding to R_p, interpolating as necessary.

In the TLU2, the above steps are followed for each channel to obtain a value of N in each channel (N_1 and N_2) for each of the five ν values. Then the following steps are taken:

5. The difference ΔN $(=N_1-N_2)$ is calculated at each ν; if $|\Delta N|<.001$ at one of the ν's, then those values of N and ν are printed out as the satellite inferred values. If ΔN has the same sign at each ν, then "No Solution" is printed out. If $|\Delta N|>.001$ at all ν's, the code goes to Step 6.

6. A new ν is selected midway between the two adjacent ν values for which ΔN has different signs.

7. At this new ν $(=\nu_M)$ steps 1-4 are followed for each channel to generate N_1 and N_2.

8. With ν_M and the two adjacent ν's (used to generate ν_M) the code returns to Step 5.

The above procedure is allowed to iterate a maximum of eleven times, at which point the code will print out "No Solution" if $|\Delta N|<.001$ as not been achieved.

The TLU2 was checked against previous hand calculations using AVHRR data acquired at San Diego and on the USNS Hayes in 1980. The comparison showed good agreement between the two methods, with some differences, as anticipated, due to the assumption of a linear dependence of radiance on ν in the hand calculations. However, in seven of the 17 test cases the code found "No Solution." This was because the data indicated that ν was outside the 2.0 to 5.0 range of the first version of the code. The code was modified to allow the three-point Lagrangian curve fit to radiances at ν = 2.0, 3.5, and 5.0 to be extrapolated to ν = 0 and ν = 7.0.

When the 17 test cases were re-run with the final version of the code, four "No Solution" results still occurred. It is unlikely that the aerosol distribution really lies outside the 0 to 7.0 range of ν values; in fact, as shown in Table 3 the ground-truth indicates $\nu = 3.57$ for the one USNS Hayes "No Solution" case (there were no multispectral ground truth data at San Diego, and thus no ground truth ν values). The "No Solution" results may be due to the extrapolation method in the code being invalid; this can be checked only by making more extensive runs (at $\nu = 0$ and 7.0) with the Dave code, but this was not considered cost-effective within the scope of the present study. It is most likely that the "No Solution" results are due to errors in the AVHRR radiance values. In fact, the AVHRR Channel 2 radiances used in these test cases are probably in error, as discussed in Section 5, and with revised Channel 2 radiances, a solution is found for the USNS Hayes "No Solution" case that gives excellent agreement with the ground truth (see Table 5 in Section 5).

Table 3. USNS Hayes Data

Date	Ground Truth		AVHRR by Hand		AVHRR by Code	
	N	ν	N	ν	N	ν
4/10/80	0.78	3.41	0.82	3.9	0.79	4.12
4/11/80	1.14	3.22	0.85	3.55	0.85	3.49
4/12/80	0.95	3.24	0.80	3.75	0.75	3.88
4/19/80	1.10	3.57	1.00	4.55	No Solution	

5. BARBADOS DATA ANALYSIS

The two-channel table look-up (TLU2) code has been used to analyze the Barbados data set. As seen in Table 4, the original ν values show poor agreement between the satellite and ground truth; the satellite N values are not much different from the single channel table-look-up (TLU1) values found in our NOAA study[4]. The results of the NOAA study had suggested that the Barbados ground truth might be in error, and this conclusion seems to be confirmed by the TLU2 calculations.

In order to investigate the possible reasons for the disagreements in the Barbados data set, it was compared with the only other multispectral ground truth data set available, viz., the USNS Hayes data. It is assumed that the USNS Hayes ground truth data are good since they showed good agreement in both N and ν with the satellite values (Table 3). In analyzing the data the following steps were taken:

1. Uncorrected AVHRR Channel 1 radiances (R_1) were plotted against Channel 2 radiances (R_2) as shown in Fig. 5 for the USNS Hayes and Barbados data, using two points from each site with similar R_1 and R_2 values. These points fall within the spread of data found for a similar plot in the NOAA study. The calculated values of R_1 and R_2 for the sun and viewing angles and N values at the times of the measured data are also shown in Fig. 5 for $\nu = 2.0$ and 3.5. It is seen that the theory shows a clear separation between the R_1 vs R_2 curves for the two ν values, as observed for the measured R_1 vs R_2 curves. This strongly suggests that the ν values at Barbados are less than ν for USNS Hayes, and probably close to $\nu = 2$ since the USNS Hayes ground truth showed $\nu \sim 3.5$.

2. The NOAA study showed that the Barbados ground truth at 500 nm was probably in error. Since Step 1 indicates $\nu \sim 2$ at Barbados, as found by the ground truth, it appears that both the 500 nm and 860 nm ground truth measurements must be in error; a positive zero offset in both channels would still give approximately the same ν value, but would increase

Table 4. Barbados Data

Date	Ground Truth (Original)		AVHRR (Original)		Ground Truth (Revised)		AVHRR (Revised)	
	N	ν	N	ν	N	ν	N	ν
7/22/80	0.55	1.78	1.03	2.88	0.92	2.02	No Solution	
7/26/80	0.65	2.13	0.60	4.86	1.06	2.25	No Solution	
7/27/80	0.50	1.76	0.70	4.30	0.88	1.98	0.98	2.02
7/28/80	1.77	2.05	1.43	3.11	2.70	2.24	1.24	2.39
7/31/80	1.07	1.90	1.51	3.20	1.60	2.00	2.07	1.47
8/13/80	0.75	2.04	1.09	3.38	1.17	2.20	No Solution	
8/14/80	1.09	2.00	1.39	3.76	1.65	2.05	1.68	2.40
8/15/80	1.71	2.07	1.46	3.25	2.59	2.25	1.25	2.59
8/18/80	0.30	1.92	0.49	4.93	0.62	2.17	1.31	0.58
8/19/80	0.92	2.07	1.02	3.52	1.40	2.20	0.97	2.32
8/22/80	0.42	1.90	0.61	4.04	0.77	2.13	No Solution	
8/24/80	0.35	1.70	0.47	2.38	0.70	1.97	0.26	0.75
8/28/80	0.55	1.86	0.97	3.30	0.98	2.00	0.82	2.05
8/31/80	0.63	1.93	1.26	2.95	1.02	2.16	No Solution	
9/ 2/80	0.50	1.93	0.85	3.70	0.87	2.10	0.72	2.80
9/ 6/80	1.07	1.93	1.45	2.89	1.59	2.03	1.13	1.88
9/24/80	0.28	1.77	No Solution		0.64	2.00	0.53	2.40
9/28/80	0.42	2.00	0.33	6.97	0.77	2.16	0.91	2.05
9/29/80	0.26	1.62	0.55	4.53	0.57	2.00	0.50	2.87
10/ 2/80	0.64	2.04	0.67	4.56	1.05	2.14	1.47	0.98
10/ 3/80	1.55	2.11	1.32	3.78	2.21	2.13	1.33	2.69
10/ 4/80	0.39	1.89	0.65	4.29	0.74	2.07	0.58	3.17
10/12/80	0.89	2.15	1.08	3.92	1.35	2.33	1.19	2.53
10/13/80	0.23	1.68	0.71	4.05	0.50	2.14	0.63	3.06
10/16/80	0.58	2.09	0.90	3.93	0.95	2.24	1.46	1.41
10/20/80	0.45	1.57	1.03	3.25	0.79	1.89	No Solution	
10/30/80	0.66	1.94	1.05	4.07	1.05	2.14	1.28	2.46
10/31/80	0.53	2.02	1.05	2.96	0.89	2.23	0.81	2.22

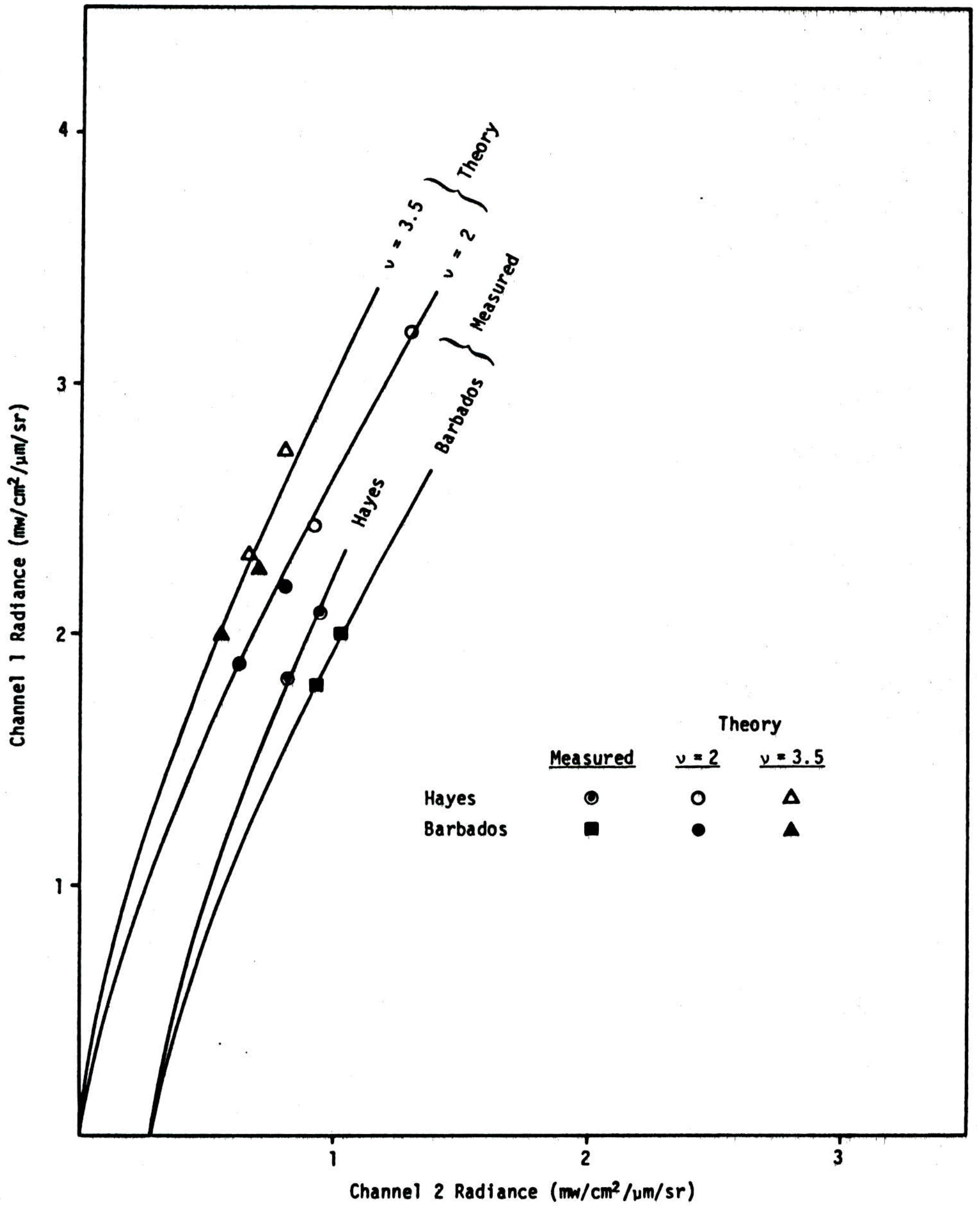

Figure 5. Measured and Calculated AVHRR Channel 1 Radiances vs Channel 2 Radiances.

N (Ground Truth) as needed to make N (Satellite) vs N (Ground Truth) agree with the TLU1 results at the other sites. An offset of 16 units (typical readings are in the 60-110 unit range) in the Barbados readings was chosen to make the N (Satellite) vs N (Ground Truth) satisfactory as shown in Fig. 6.

3. The possibility of an instrument offset was discussed with T. Snowdon (University of Miami) who had provided the sunphotometer for the Barbados site. He said this could occur only if one of two batteries in an amplifier is low, and that it would be the same offset in the 500 nm and 860 nm channels. He checked the records of this particular sunphotometer, and found that it did indeed have one low battery when returned from Barbados! Of course, there is no way of knowing when the battery failure occurred, but the instrument switch could have been left on early in the measurement program; Snowdon said a low battery would not be detected as a drift in the readings in the daily sequence of three readings. Snowdon could not estimate the actual magnitude of the offset deduced in Step 2 without conducting some special experimental tests.

4. The offset deduced in Step 2 was applied to both the 500 nm and 800 nm channels, and the ground-truth values of N and ν were recomputed. As seen in Fig. 6 and in Table 4, the N's agree much better with the AVHRR N values, but there is still poor agreement in the ν values.

5. So far, TLU1 gives a good plot of N (Satellite) vs N (Ground Truth) using AVHRR Channel 1 radiances corrected as in the NOAA study, and the ground truth corrected as in Step 4. In addition, the corrected ground-truth gives $\nu \sim 2$ as indicated by the AVHRR data in Step 1. Thus, referring to Fig. 5, it appears that the curve for the measured Barbados data needs to be shifted to the theoretical curve for $\nu = 2.0$. This can be done by adding 0.5 mw/cm^2/μm/sr to R_1 (as found in the NOAA study), and subtracting 0.1 mw/cm^2/μm/sr from R_2 (0.25 mw/cm^2/μm/sr was inferred in the NOAA study using more limited calculations). These revised R_1 and R_2 values were used in TLU2 to compute the satellite values of N and ν shown in

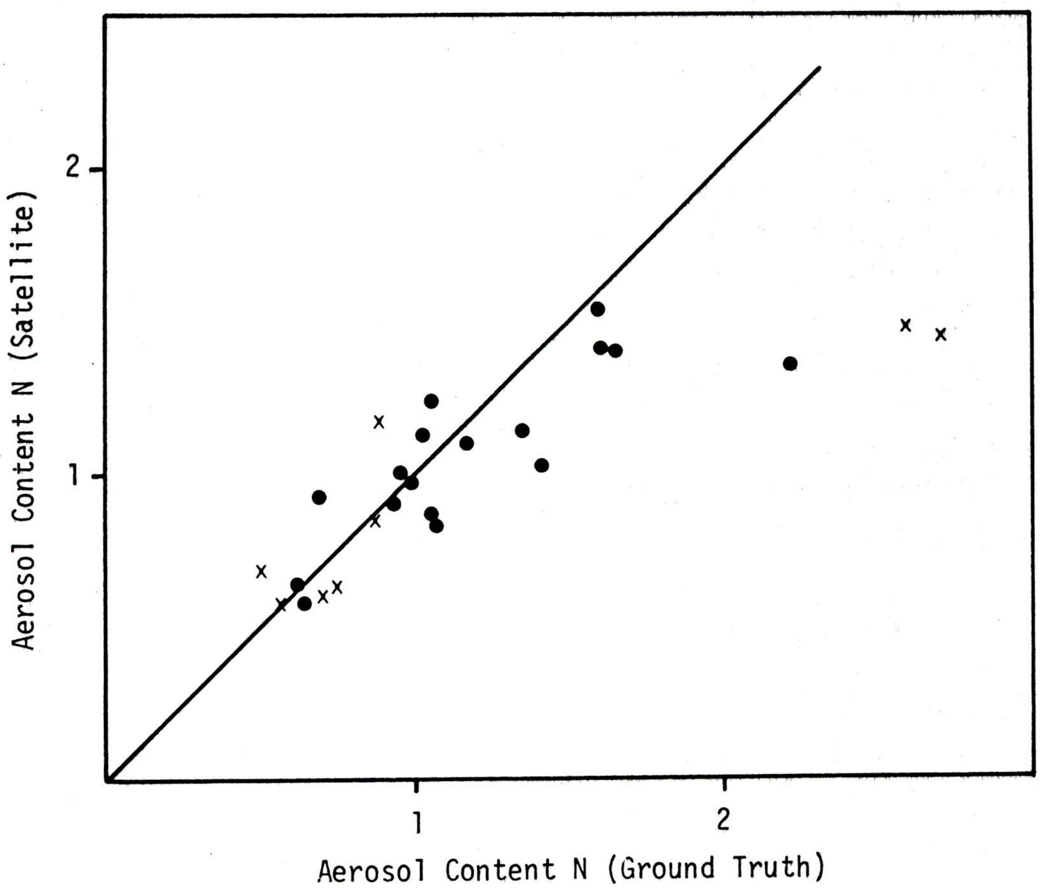

Figure 6. Comparison of Satellite (TLU1) and Adjusted Ground Truth Measurements of Aerosol Content at Barbados (x indicates $\theta_o > 70°$).

Table 4 and in Figs. 7 and 8. The results for the USNS Hayes using the new AVHRR radiance corrections are also shown for comparison in Table 5 and Figs. 7 and 8.

These results are very encouraging. The N (Satellite) vs N (Ground Truth) shows more scatter than found with TLU1 (Fig. 6). However, the ν (Satellite) values show remarkably good agreement with ν (Ground Truth) considering the uncertainties in both the satellite and ground truth data; about two-thirds of the data points in Fig. 8 show ν (Satellite) within 0.5 of ν (Ground Truth). It should be noted that Fig. 8 does not include the six no-solution cases (see Table 4) which are attributed to errors in R_1 and R_2. It is anticipated that with high quality multispectral ground truth data this agreement would be improved, although the effect of AVHRR errors has not been fully evaluated yet. Some preliminary calculations in our ONR study have indicated that a 7% error in R_2 will cause 0.5 error in ν, and this happens to be approximately the uncertainty in R_2 due to the unknown water vapor absorption. In an operational system the water vapor content of the atmosphere would probably be available, so that a more precise correction to R_2 could be made, thus improving the ν determination.

Table 5. USNS Hayes Data (Revised)

Date	Ground Truth		AVHRR		AVHRR (Revised)	
	N	ν	N	ν	N	ν
4/10/80	0.78	3.41	0.79	4.12	0.71	2.89
4/11/80	1.14	3.22	0.85	3.49	0.70	2.73
4/12/80	0.95	3.24	0.75	3.88	0.63	3.11
4/19/80	1.10	3.57	No Solution		0.84	3.31

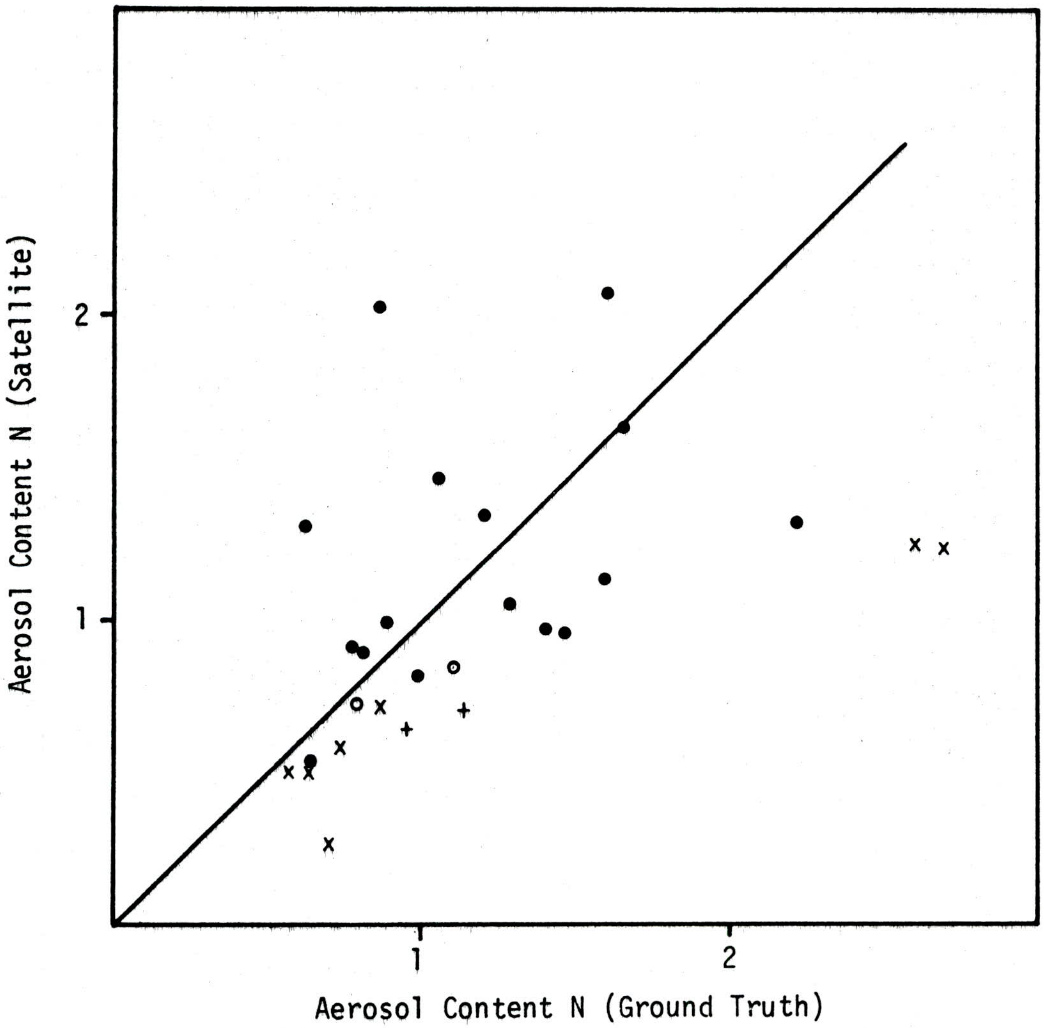

Figure 7. Comparison of Satellite (TLU2) and Ground-Truth Measurements of Aerosol Content [• x(θ_o > 70°) Barbados; o +(θ_o > 70°) USNS Hayes].

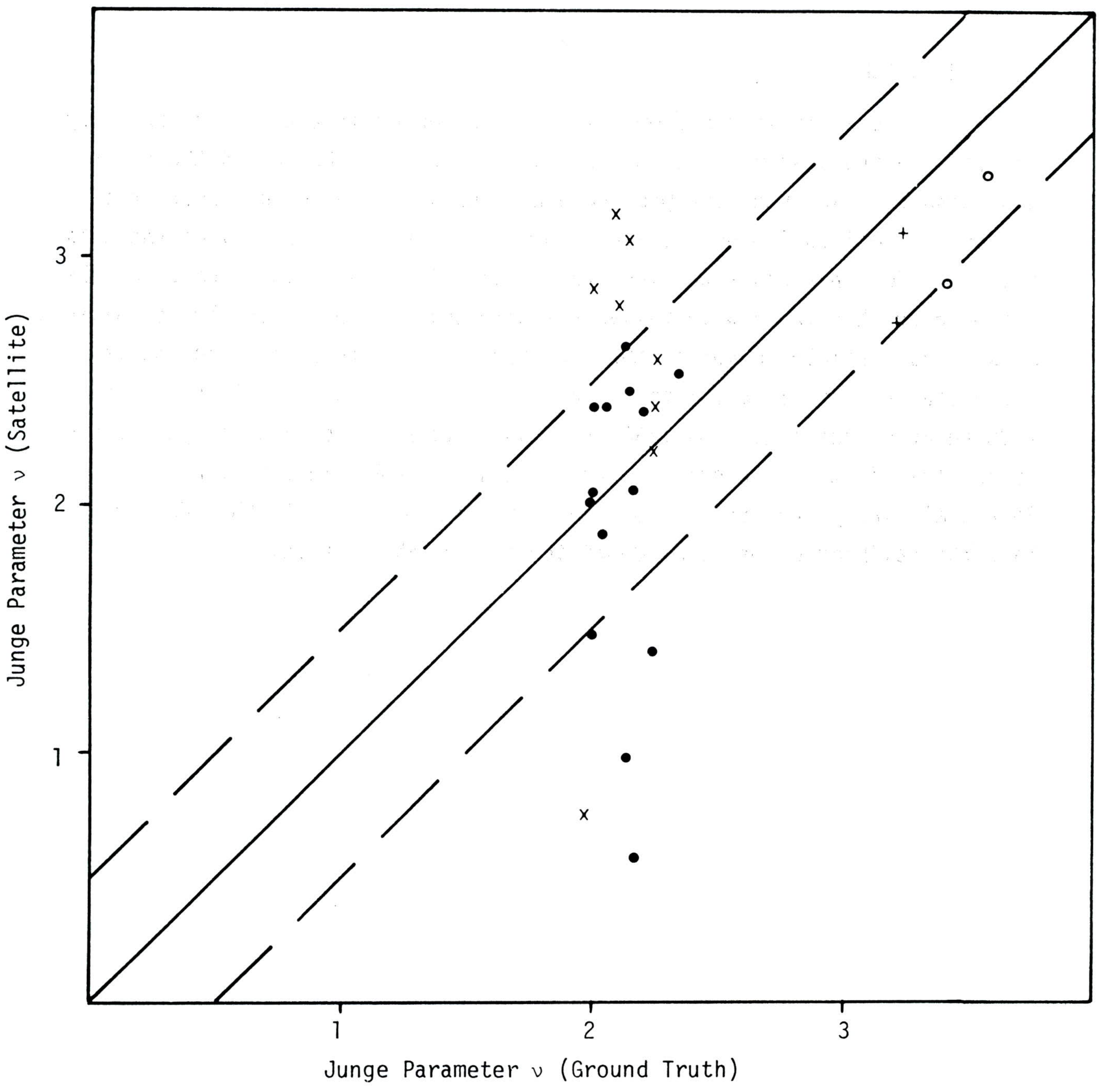

Figure 8. Comparison of Satellite and Ground Truth Measurements of the Junge Parameter [• x ($\theta_o > 70°$) Barbados; o + ($\theta_o > 70°$) USNS Hayes].

6. CONCLUSIONS

The analysis has shown, in spite of uncertainties in the accuracy of both the ground-truth and the satellite data, that the AVHRR Channel 1 and Channel 2 radiances can provide useful estimates of ν to support the aerosol content estimates previously demonstrated. The quality of the data available for this study was less than desirable, and it is recommended that a ground-truth network with reliable instruments and observers be established as soon as possible to verify the two-channel analysis on a global basis. The preferred satellite for the experiment would be the NOAA-7 which has a 1430 equator crossing. The 1430 orbit would permit observations year-round rather than just in the summer months, as with NOAA-6 in our NOAA study. Some preliminary analyses at NOAA indicate that the NOAA-7 AVHRR does not have the calibration problem identified in our NOAA-6 study.

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